This paper, the third in the Rural Telecom Educational Series, was produced by the Foundation for Rural Service and authored by GVNW on behalf of FRS, to help readers recognize that without the underlying wireline network, wireless networks could not exist in their current form.

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WIRELESS NEEDS WIRES:

THE VITAL ROLE OF RURAL NETWORKS IN COMPLETING THE CALL

Adoption of mobile wireless services in the United States has been extensive, and it continues at a high rate. While the majority of the population uses wireless services to one degree or another, federal policies continue to inhibit their ability to fully do so, particularly in rural markets where wireless service would potentially make its most important contribution to the public's productivity, lifestyle and security. Rural wireless service providers face tremendous challenges to their future viability. Perhaps the greatest challenge confronting them, as well as all wireless service providers, is the uncertainty surrounding the backbone of their service – the wired public switched telephone network (PSTN) – and whether it will remain functionally capable of carrying their traffic. The decisions made by policy-makers on such issues as funding for universal service, spectrum and competition will have a telling affect on the future of wireless systems in rural America and, more importantly, on the health of the entire rural telecommunications industry.

Since the inception of modern commercial mobile radio service (CMRS) in 1983, the U.S. wireless industry's customer base has grown to 200 million, or two-thirds of the population. This growth has been particularly rapid over the last few years, with the customer count doubling between 2000 and 2005. At the same time, there has been a marked reduction in landline telephone access lines, with the FCC reporting mid-year 2004 losses of 1.2% per quarter. By the end of 2004, wireline line counts had been significantly surpassed by wireless. There are increasing indications that some of the reduction in wireline services relates to consumers replacing, rather than supplanting, part of their traditional wireline services with wireless phones. While there are no precise numbers to support this claim, various estimates indicate that somewhere between 3% and 5% of the U.S. population have already replaced their wireline service with wireless. One study referenced in the FCC's *Tenth Annual Report and Analysis of Competitive Market Conditions with Respect to Commercial Mobile Radio Service* indicates that more than 5% of all adults and 14% of 18-24-year-olds live in households with only wireless service.

Even in rural markets, where cellular service did not get started until the early 1990s, adoption of wireless has been high. In rural regions of the country with average population densities of less than 10 people per square mile, the FCC reported 2004 penetration rates of 43% to 64%. The FCC's report also indicated an average of nearly four wireless competitors for all counties with population densities of less than 100 people per square mile. While these statistics give the impression that rural America is well served by wireless, they are somewhat misleading. In many counties, wireless coverage is provided by one or more national or regional service providers, and is limited to only a small portion of the county, such as a highway that crosses the county or the only town with any concentration of population. In cases like these, coverage is provided mostly to allow urban customers of those large carriers to have service when they travel there. Beyond those areas, coverage in the county may be spotty or nonexistent, yet local residents still may utilize wireless service when they travel.

Community-based telecom providers generally have the greatest interest in and incentive to provide wireless service in such rural communities. While such factors as low population density, terrain and the lack of economies of scale present major challenges to establishing a positive business case, there are many rural service providers that have successfully entered the wireless business. However, the challenges continue to grow.

WIRELESS NEEDS WIRES

In order to understand the challenges faced by rural mobile carriers, it is helpful to understand the basic design and operation of mobile wireless networks. Most importantly, one must understand the interrelationship of these systems with, and dependence on, the PSTN. For purposes of this paper, we will focus on mobile wireless systems licensed to operate in the 850 MHz frequency band, known by the industry as "cellular systems," and systems licensed to operate in the 1900 MHz band, generally known as "personal communications systems" or "PCS," and refer to these systems as "wireless." Because of their similar designs, the term "cellular" will be used generically to represent both, unless specifically noted otherwise.

Today's wireless networks are extremely complex amalgamations of electronic data processors, databases, switches, radios and transport elements. Underlying this complexity, however, are a few relatively simple concepts. The basic cellular design was conceived in the late 1940s to address the inefficiencies of early mobile radio systems, which could only serve a small number of simultaneous users, even in the largest of cities. Each channel in those early systems covered an entire urban area, and could be used by only one customer at a time. In contrast, the cellular design could serve many customers throughout an urban area simultaneously by incorporating two concepts:

1. **Frequency Reuse** – By using several low power radio sites to cover a geographic area, each radio channel could be used multiple times without creating interference, as long as the same channel was not used by two adjacent sites. The incremental coverage area provided by each radio site is known as a cell, and the system is said to use a cellular architecture.

2. **Handoff** – Because of the small coverage area of each cell, user mobility would be severely limited without the ability to transfer a conversation from cell to cell as the user traveled around the system coverage area. That ability to perform a handoff of the communication from cell to cell would require continuous communication between the user's processor-driven mobile phone and a coordinating central control center that also could send instructions to each cell site radio.

While the new cellular design was an improvement over the basic design, there was one problem with it. It required a high degree of control processing, which was not achieved until the 1970s with development of microprocessors. The first commercial system did not become available until 1983.

Present day wireless networks consist of elements that are entirely analogous to components of any other current communications systems available to the general public, whether PSTN, Internet, satellite or cable. The four basic components are:

1. **Cell phone** – A device used by the customer to communicate with the network and other users. A cell phone is used primarily for voice services, but this function is increasingly provided by devices that include other features, such as Internet access,

text messaging, e-mail capability with keyboard input, and still or streaming video options.

2. **Cell sites** – The means by which a customer can connect to the network. This is a radio transceiver system that generally corresponds to a wireline local exchange carrier's local loop.

3. **Mobile switching center (MSC)** – The "brains" of the network that controls all elements of the wireless network and provides a means of routing cellular customers' communications to their intended destinations.

4. **The interexchange switching and transport network** – Connects the wireless network to other wireless or wireline networks.

Contrary to public perception, a wireless network does not stand alone. It may be more appropriate to think of a wireless network as one of a large number of gateways to the highly interconnected and interdependent network of elements making up the national and global telecommunications infrastructure. Truly, much of what makes up the nation's wireless networks is provided by the wireline local exchange carriers and interexchange carriers that make up the PSTN. *It is essential to note that the viability of wireless networks is entirely dependent upon the ongoing availability of the wireline networks that actually serve as the backbone.*

THE CELL PHONE

Today's cellular communications device is essentially a computer controlled radio system. It is able to decode the digital information it receives and encode voice and other information being sent by its user. Through communications with the cellular network, it can control its transmission output power, change frequencies during the course of a call, and perform complex calculations necessary to validate its authenticity. When the cell phone is turned on, it searches for the strongest compatible signal from nearby cell sites, and regardless of whether or not a call is in process, it maintains constant contact with the network, so that it may be reached wherever it happens to be at all times regardless of the location. In addition, the phone must be able to provide processing power for whatever collection of voice, data, and multimedia services provided by its manufacturer and the customer's wireless service provider.

Early cell phones operated in the 850 MHz cellular frequency band and featured analog transmission. Those that were installed in automobiles generally used a transmit power of 3 watts. As cell phones became smaller and more portable, and PCS frequencies and digital transmission capability were implemented, engineering needs and safety concerns led to much reduced power levels; current cell phones have maximum power output of around 0.6 watts. While the sensitivity of receivers at cell sites has improved significantly, many rural users have observed a reduction in coverage as they switch over to newer phones. In addition, rural wireless service providers have experienced a substantial amount of customer resistance to programs to move users to the more spectrally efficient digital phones. For better or worse, however, this issue will be resolved as carriers phase out analog service, which current regulation will allow beginning in early 2008. While some carriers may not immediately eliminate all analog channels, customers that continue to use analog phones will see their available coverage reduced drastically. Once the phase out begins, it is highly likely that major urban areas will have no analog channels at all.

As the transition occurs, cell phone supply will prove challenging. Already, some small local wireless providers have experienced an inability to purchase the newest, most popular and fully featured phones for their customers. Large national carriers, some of which are experiencing growth in their customer base by more than 1 million customers each quarter, are able to make volume commitments to manufacturers thousands of times greater than small companies having only a few thousand customers. In doing so, larger carriers are able to control the supply of those phones. Although some smaller carriers have formed purchasing consortia to achieve a greater volume, with the magnitude of national carriers' purchases, they are not likely to obtain the most desirable phones at competitive prices.

CELL SITES

In the simplest terms, a cell site is a radio system that connects a cell phone located in a relatively small geographic area (known as a cell) to the mobile wireless system. Coverage for a cell site might range from part of a city block in a large urban market, to a 250 square mile area in a rural surrounding with low population density. The wireless carrier places enough cell sites to provide coverage to its intended service area, but making this determination is not necessarily easy. Engineering and political considerations, which typically lead to an average cell site cost between $200,000 and $500,000, weigh heavily in such decision making.

Generally, a wireless carrier wants to locate cell sites close enough to each other to ensure mobile customers may travel from cell to cell without experiencing a break in coverage and the resultant "dropped call." The carrier also wants to ensure that every customer who wants to place a call is provided service. Consequently, because a cell site's capacity for calls is limited, the carrier may be required to build more cell sites than would be required simply for geographic coverage.

There are a number of other engineering and political factors that affect the cell site's placement and designed coverage area. Some examples:

1. Transmissions on PCS frequencies will not carry as far as those on the lower cellular frequency range, all other factors being equal. PCS systems typically require four times as many cells as cellular systems.

2. Antennas placed on tall towers provide better coverage than those on shorter towers.

3. Obstructions between the cell site and the customer, such as terrain, buildings and other structures, foliage and weather, can reduce coverage.

4. It is possible to design a cell site that provides a strong signal at a very great distance, but that does no good if a normal cell phone transmitter is too weak to be received by the cell site at the same distance.

5. Political resistance in certain areas from those who are concerned about the appearance of towers in their community or the potential health effects of radio transmissions from new cell sites may deter carriers from using sites that are optimal from an engineering viewpoint.

Nationwide, the industry has built more than 175,000 cell sites; each one is connected to an MSC so that calls and control information can be delivered to their destination. These connections may cover very long distances, even hundreds of miles, and use a variety of facility types. Sometimes the wireless carrier will build its own microwave routes. More commonly, these interconnecting circuits use land-based wireline facilities that are provided by local exchange telephone companies and interexchange carriers.

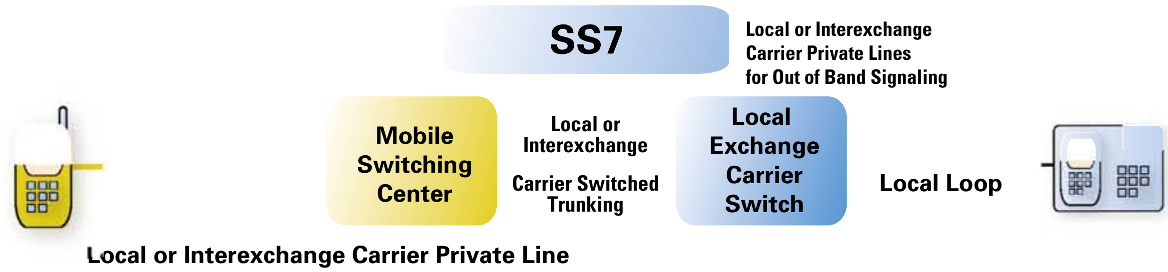
MOBILE SWITCHING CENTER

As mentioned earlier, the MSC is the control center, or the brains, of the wireless system. It includes switching functionality to connect a mobile call at a given cell site to one on another cell site, or to another wireless, wireline or data network. It also includes databases to track the status of the wireless carrier's customers, as well as other carriers' customers who are using the system. In addition, it controls the function of the cell sites and cell phones currently connected to the system.[1] The MSC keeps track of all billing and usage data, and houses all system administrative and operations functions. In order to connect and control calls to other mobile or landline networks, the system exchanges control messages with those networks over signaling facilities independent of the facilities that actually transport the calls.

When a wireless customer originates a call, the called phone number is sent from the cell phone through its connection to the cell site to the MSC. Using that information, the MSC establishes a connection to the call's destination, and from that point on must continue to provide directions to the cell phone for the duration of the call. Because of the phone's mobility, the system must monitor and adjust the phone's transmission power levels to maintain the quality of the call. As the phone travels toward the edge of a cell site coverage area, the system may identify a nearby cell that would provide better signal quality and instantaneously instructs the phone to change frequencies and transfer the call to the new cell site coverage area. This process, known as a handoff, happens so quickly that it is not recognizable by the phone's user.

[1] For purposes of this paper, we have simplified the standard network model that identifies separate network entities for the various functions described here.

FIGURE 1: Local call from mobile phone to landline phone.



(Network elements provided by wireless carriers are shown in yellow.)

One of the more complex functions of the MSC is management of the wireless customers' use of service while traveling beyond their service providers' coverage area, known as roaming. When a customer originates a call outside his home service area, or continues a call originated in his home service area while traveling into another service area, the MSCs controlling the two coverage areas communicate to establish the customer's identity and validity, share information on the customer's service features and, if necessary, reroute a call already in progress. While the customer is outside his home service area, the MSC serving the area where the customer is traveling keeps track of the status of the cell phone, and reports any changes back to the customer's home system.

While a mobile customer is roaming, an incoming call to his number may be forwarded to his location through the interaction of the home and distant MSCs. If the customer's phone is busy or otherwise unavailable, the inter-MSC messaging will allow the call to instead be routed to a voice messaging system or a recorded message.

As with facilities connecting the cell site with its MSC, the facilities used to deliver control messages between two MSCs, and similar messages that control calls delivered between the wireless network and wireline networks, are almost entirely provided by local exchange telephone companies and interexchange carriers.

THE INTEREXCHANGE SWITCHING AND TRANSPORT NETWORK

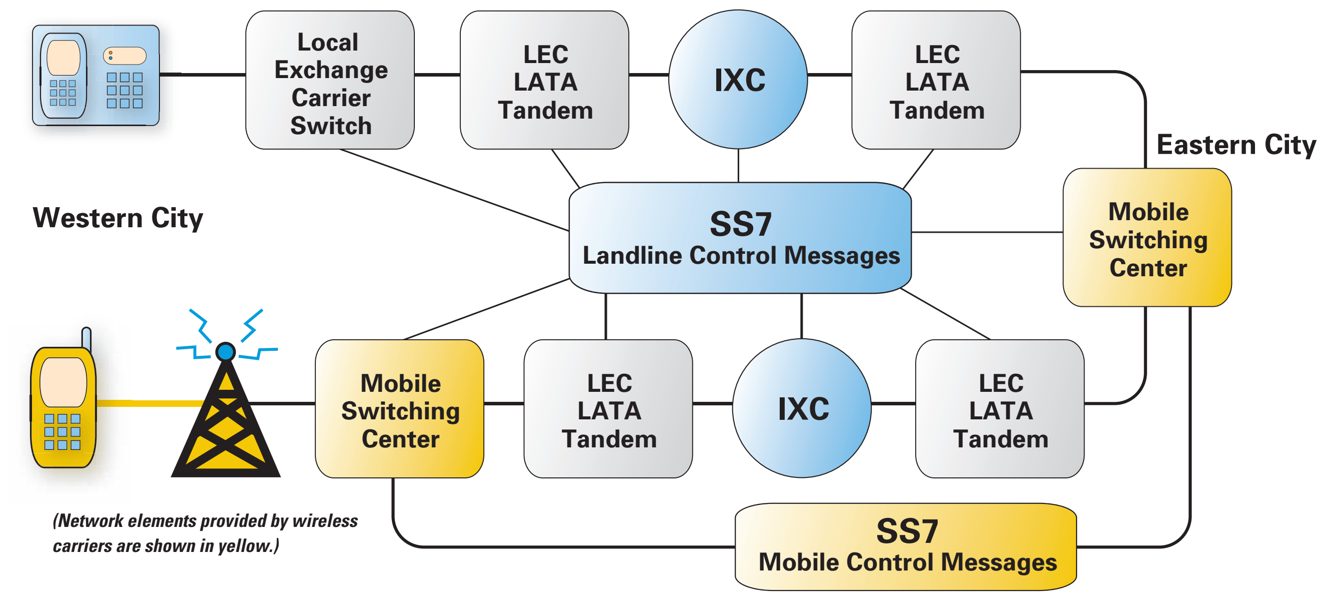
When a customer's call originates from a cell phone and terminates beyond his service provider's network to a wireline customer or another mobile service provider's customer, or when a customer receives a call originating from beyond his service provider's network, it almost certainly will be delivered over switched trunk facilities provided by wireline local exchange carriers and possibly an interexchange carrier. As with roaming control messaging, the networks involved in such calls cooperate to establish all the necessary connections for the call by using signaling networks provided by wireline carriers.

In order to better envision the interdependence of wireless and wired networks, it may be useful to visually trace two examples of cellular calls.

Figure 1 illustrates the facilities involved when a cellular customer calls a landline phone in the wireless service provider's "local calling area."[2] When the cellular customer initiates the call, the destination information is transmitted to a nearby cell site over a wireless connection to that site. That information is sent from the cell site to the serving MSC, which may be as far as hundreds of miles away, using dedicated facilities that are most often provided by wireline carriers. The MSC uses a separate signaling network

[2] A wireless carrier's local calling area with respect to interconnected networks is defined as the major trading area (MTA) in which it provides service. MTAs are quite large. The continental United States is covered by only 46; and each one covers many wireline local exchanges.

FIGURE 2: Call from landline phone in Western city to Mobile phone from Eastern city roaming in Western city.



to communicate with the terminating wireline local exchange carrier to determine if the landline phone is busy. If the phone is available, the MSC will connect all the necessary circuits across network elements provided by wireless, local exchange and possibly interexchange carriers in order to complete the call.

A second call, somewhat more complex, is depicted in Figure 2. This example shows a call being placed from a landline phone in a western U.S. city to a cell phone served by a wireless system in the eastern United States. The cell phone, however, is physically located in the western city, and is roaming on a wireless system that covers the city. When the call is initiated, it appears to the serving wireline network like any other toll call. The local exchange carrier, in conjunction with a signaling network used for the transmission of call routing instructions, sends the call over the PSTN to the eastern city MSC of the wireless carrier that provides service to the cellular customer. When the MSC receives the call, it determines from its database that the cell phone is operating in the western city. Through a control network used for delivery of messages between cellular systems, it requests routing information from the western city MSC, which assigns a temporary local number to the cell phone and provides that number to the eastern MSC. The eastern MSC then essentially places a second toll call back across the country to the temporary number assigned to the cell phone in order to complete the call.[3]

Without question, wireless needs wires. It is clear that wireless networks cannot exist today without the underlying wireline facilities provided by local exchange telephone companies and interexchange toll carriers. In fact, the basic examples here represent only the tip of the iceberg. Many additional functions and features of wireless networks depend on landline facilities. Internet access, e-mail and content services, including video and music, will most likely continue to depend on wired networks for transport to wireless carriers and their customers. Other functionality required by

[3] It is interesting to note that this call is, in effect, a local call – the landline and cell phones could be physically located across the street or even in the same building. Interexchange carriers, however, receive revenues for two cross-country toll calls.

the government, such as CALEA (Communications Assistance for Law Enforcement Act), E911, and number portability, also depend on wired networks. As the existing communications services continue to migrate to Internet protocol (IP), and new IP-based services are born, the interdependence of networks will become increasingly complex.

In addition to the interdependence, it also is important to recognize the complementary nature of mobile wireless networks and wired networks. For example, while wireless provides the freedom of movement that can never be duplicated by wired networks, wired networks have the long-term advantage of providing the extremely high capacity that likely will be required of future telecommunications and multimedia applications, and the capability of delivering communications to locations that wireless cannot.

Landline facilities will almost certainly continue into the future to be integral to the services provided by wireless carriers. While wireless carriers could build their own facilities to replace much of what is provided to them by wireline carriers, that approach would make very little sense. For one, the capital costs of duplicating the high-quality facilities built by the wireline industry over a period of many years would be exorbitant. There also is no reason to believe that such a feat could be accomplished in any reasonable length of time. By utilizing existing landline resources, wireless carriers also avoid the need for management and operations resources necessary to maintain those facilities. Possibly most importantly, avoiding the need to focus resources on such activities allows wireless carriers to focus on their real business of developing and marketing services.

WIRELESS CHALLENGES IN RURAL AMERICA

The interdependence of wireless and wireline networks must be recognized in all parts of the country, but nowhere is it a bigger issue than in rural America. The provision of wireless service there is difficult at best, so the health of the underlying network that allows it to exist is of potentially greater concern than in the more urban parts of the country.

There are a number of serious challenges that must be addressed by every rural wireless service provider, particularly the “costs of rural” that come with the territory, specifically low population density and difficult terrain. Low, and in many cases decreasing, population density causes higher capital costs and network operating expenses per potential customer. As a somewhat oversimplified example, an urban area with population density of 1,000 people per square mile may have a cell site that covers 75 square miles, providing a carrier with the opportunity to address 75,000 potential customers. That same cell site, with a similar level of investment and operating expense, might cover only 75 to 750 potential customers in many rural areas. The terrain of many rural areas also is more difficult to serve than the terrain found in the majority of major urban areas. The combination of these two factors makes the business case for providing wireless services in rural America difficult at best, especially when you take the industry's rapid development of new technologies and services into account.

Nevertheless, community-based telecom providers have been successfully overcoming these challenges. In fact, most are either providing wireless services already or considering how they will do so in the future. Through such means as stringent control of costs, partnering with others to share network infrastructure and achieve purchasing scale, closely targeting the needs of customers and even acquiring used equipment on eBay, they have managed to succeed in providing new services to their communities.

Beyond the natural challenges of serving a rural environment, there are a number of problems facing rural wireless service providers that ingenuity may not allow them to solve on their own. Two of those areas of concern are spectrum availability and roaming.

SPECTRUM AVAILABILITY

In order to provide mobile wireless service, a wireless carrier must have licensed spectrum. Though not easy, many rural telecommunications providers obtained the necessary spectrum in the FCC's cellular rural market lotteries and PCS license auctions during the last 15 years. Today, as they consider expanding their systems, and as others consider entering the wireless marketplace, they are finding it extremely difficult to obtain the necessary spectrum licenses—even when existing licenses are not being fully utilized in the desired geographical area.

Because of the nature of cellular band licensing, in which a licensee stands to lose unserved portions of its license area, the spectrum is generally fully utilized. PCS licensing rules, however, allow a licensee that covers defined percentages of the population of its license area to retain the unserved remaining geographic area. While the FCC has established rules that allow such licensees to transfer or lease unserved license areas to rural carriers interested in providing service there, the licensee has no strong incentive to do so. Under today's rules, the licensee may simply "bank" the spectrum for some undesignated future use.

Until licensing rules are modified to ensure that unused spectrum is made available to others willing to use it, this wasteful situation will likely continue, leaving some areas of the country without any meaningful wireless service.

ROAMING

Rural wireless carriers are dependent on roaming agreements with other carriers to provide customers with the ability to use wireless service as they travel in other parts of the country. That capability is expected by the vast majority of wireless customers. Without it, the wireless carrier would have a very limited potential customer base. Changes in the structure of the wireless industry over the last several years, however, have drastically changed the nature of roaming relationships between rural and national wireless carriers. National and regional carriers have significantly increased the size of their coverage footprints, and the number of carriers has been reduced with a number of mergers and acquisitions. With that consolidation, the number of potential roaming partners for rural carriers has dwindled. In addition, the increased footprints of national carriers have reduced those carriers' dependence on rural carriers for roaming. When their customers travel, they continue to use their carrier's systems.

The result is that rural carriers have experienced extreme difficulty in obtaining fair roaming treatment. Many have reported that when agreements have been available, the larger carrier has required the smaller carrier to pay a rate several times higher than what competitive conditions will allow the rural carrier to charge its customers. At the same time, the large carrier has forced the rural carrier to charge a very low rate, even below cost, when the large carrier's customers roam on the rural system. The rural carrier's resultant loss in revenue and increased expenses, or alternatively, its loss of customers, unfairly endangers its financial well-being, and could potentially force it out of business. If the problem persists, rural consumers would be left without wireless service, and those visiting such areas would be without wireless access.

THE FUTURE OF RURAL SERVICE

Without thoughtful consideration by policy-makers of the challenges of providing wireless service in rural America, as well as the dependence of wireless services on wireline networks, portions of the nation are likely to remain underserved, and the fiscal health of existing rural networks will continue to be challenged.

Most importantly, one must recognize that without the underlying wireline network, wireless networks could not exist in their current form. In spite of this obvious fact, large wireless carriers and policy-makers alike continue to pursue practices and policies that will in fact undermine the critical wireline network. While discussions on how to modify reciprocal compensation, access charges and universal service continue, attention must be placed on ensuring these mechanisms are capable of maintaining the fiscal health of that wireline network. America's economic and national security truly depend on the maintenance of a nationwide integrated communications system, which not coincidentally is the very essence of the nation's longstanding commitment to universal service goals.

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